The conservation of large timber structures *

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SUMMARY: *Much of the early development of Australia utilised timber infrastructure, such as bridges, jetties and large buildings. While many of those early structures have disappeared forever, enough interesting ones remain to pose the question of what to do about them. The maintenance of timber is not widely understood, and conservation of significant old timber structures is usually seen as an expensive, short-term "fix", generally involving considerable replacement of the original elements. Fortunately, over the past 20 years there has been considerable development of preservation technology and assessment methodology for timber road bridges by Main Roads Western Australia – and these techniques are applicable to the majority of timber structures. In keeping with modern environmental concerns, the timber preservation methods have been chosen for minimum environmental impact and simplicity of application. This paper outlines the principles of timber preservation and details the application of the current bridge management methods to large timber structures generally. The author has been intimately involved in both the establishment of the preservation methods, as well as their use in large bridge refurbishment projects.*

1 INTRODUCTION

The first structures built in Australia by Europeans necessarily used local building materials, particularly native timbers. Their ease of use, combined with the good durability of most native timbers, meant that most of the early buildings were largely or entirely constructed from timber. Of course, most of those structures no longer exist, but a few early ones survived, along with a selection of what has been built since. The management of the older timber structures is often seen as difficult and expensive, or involving unacceptable levels of risk to the public as they are exposed to the hazards of deteriorated timber elements.

The evolution of building materials has seen a remarkable variety emerge in the fabric of the structures used to support our lives – from stone, masonry and brick to steel, concrete in its many forms, plastics, glass, textiles and now the modern super-strong composites. Despite its small environmental footprint, timber has diminished in use for larger structures, and the knowledge of its proper handling and preservation has almost disappeared too. There has of course been some impressive engineering of large timber bridges and industrial timber framed buildings, especially in Europe – with most relying on developments such as Glulam (glued laminated timbers) or composite design to achieve the span lengths and the strengths now requested.

In some parts of the world, where the native timbers have good natural durability and many old structures remain in use, there has been an economic imperative to extend the service life of older structures, such as timber bridges, because of the prohibitive costs associated with large-scale replacement. Western Australia (WA) is such a place, with native hardwood timbers such as Jarrah and Wandoo being famous for their durability, allowing structures such as bridges to typically stay in service for 60 to 100 years with minimal maintenance. The methodology developed in the past 20 years as the mainstay for maintaining WA timber road bridges is widely applicable, and is presented here as a general basis for conservation of large timber structures.

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2 PRINCIPLES OF TIMBER DETERIORATION

There are two types of deterioration in timber – biological and non-biological. The main agents of biological attack are fungi, termites and marine organisms. The main causes of non-biological attack are corrosion of fasteners, shrinkage and splitting, and fire.

2.1 Fungi

Severe internal decay of timbers used for bridge structural members is caused by "white rot" or "brown rot" fungi. External surface decay, especially in ground contact areas, is caused by "soft rot" fungi. Other fungi, such as mould and sapstain fungi, may produce superficial discolouration on timber but are generally not of structural significance.

Fungal growths will not develop unless there is a source of infection from which the plants can grow. Fungi procreate by producing vast numbers of microscopic spores, which may float in the air for long periods and be blown for considerable distances. Although it is fair to say that no timber in service will be free from decay because of an absence of infecting spores, these spores will not germinate and develop unless there is:

- an adequate supply of food (wood cells)
- an adequate supply of air or oxygen. Note that prolonged immersion in water saturates timber and inhibits fungal growth.
- a suitable range of temperatures. Optimum temperatures are 20 to 25 °C for soft rots, while their rate of growth declines above or below the optimum. Soft rots have a greater tolerance of lower temperatures and many survive at temperatures down to 0 °C.
- a continuing supply of moisture. Wood with a moisture content below 20% is safe from decay, and many fungi require a moisture content above 30%.
- Once established, the decay fungi continue to grow at an accelerating rate as long as favourable conditions prevail. Depriving the fungus of any one of these required conditions will effectively curtail the spread of decay. Wood that is kept either dry or saturated will not rot. Moisture change can affect decay indirectly because drying often leads to surface checks, such as cracks or spalls in the timber, which may expose untreated sections of timber or create water-trapping pockets. Proper preservative treatment effectively provides a toxic barrier to the decay fungi's food supply, thus preventing decay.

2.2 Termites

WA has a large number of different species of termites that are widely distributed. Heavy termite attack is found in the northwest regions of the state (particularly due to the feared species *Mastotermes Darwiniensis*), but the hazard is still sufficient in the southern regions to constitute a significant problem.

Practically all termite damage to large structural timbers occurs through subterranean termites (especially *Coptotermes acinaciformis* and allied species), which require contact with the soil or some other constant source of moisture.

Termites live in colonies or nests that may be located below ground in the soil or above ground in a tree stump, hollowed-out structural member or an earth mound. Each colony contains a queen, workers, soldiers and reproductives (alates). The workers, who usually constitute the highest proportion of the colony population, are white-bodied, blind insects some 3-6 mm in length, featuring well-developed jaws for eating timber. Attack by subterranean termites originates from the nest, but may spread well above ground level, either inside the wood or via mud-walled shelter tubes called galleries, which are the termites construct on the outside of timbers. These galleries are essential for termites, which require an absence of light, a humid atmosphere and a source of moisture to survive. At least once a year in each colony, the alates develop eyes and wings, and leave the nest under favourable weather conditions to migrate up to 200 m from the original nest. After migration, their wings fall off and a few of these may pair to start new colonies.

Termite attack, once established, usually degrades timber much more quickly than fungi, but it is rare for termite attack to occur in the durable hardwoods (such as Jarrah, Wandoo and Blackbutt) normally used in WA timber construction, without some pre-existing fungal decay. This decay accelerates as the termites extend their galleries through the structure – moving fungal spores and moisture about with their bodies. Hence, although most of the material removed by termites has already lost its structural strength because of decay, the control of termite infestations remains an important consideration.

Basically, there are two main strategies in termite control:

- Eradication of the nest, by either direct chemical treatment or by separation of the colony from its sustaining moisture.
- Installation of chemical and physical barriers to prevent termites from entering a structure or attacking timber in contact with the ground.

In practice, it has often been difficult to eradicate the nest because of the problem of locating it.

2.3 Marine organisms

Damage to underwater timber in the sea or tidal inlets is usually caused by marine borers, and is more severe in tropical and sub-tropical waters than in colder waters (such as the Australian southern shoreline).

The two main groups of animal involved are:

- Molluscs (Teredinindae) – this group includes various species of Teredo, Nausitora and Bankia. They are commonly known in Australia as teredo or "shipworm". They start life as minute, free-swimming organisms, and after lodging on timber they quickly develop into a new form and commence tunnelling. A pair of boring shells on the head grow rapidly in size as the boring progresses, while the tail with its two water-circulating syphons remains at the original entrance. The teredine borers destroy timber at all levels from the mudline to high-water level, but the greatest intensity of attack seems to occur in the zone between 300 mm above and 600 mm below low tide level. A serious feature of their attack is that, while the interior of a pile may be practically eaten away, only a few small holes may be visible on the surface.
- Crustaceans – this group includes species of Sphaeroma (pill bugs, similar to garden slaters), Limnoria (gribbles) and Chelura. They attack the wood on its surface, making many shorter and narrower tunnels than those made by the teredines. The affected timber is steadily eroded from the outside by wave action and the piles assume a "waisted" appearance or "hourglass effect". Attack by Sphaeroma is limited to the zone between tidal limits, with the greatest damage close to half-tide level. They cannot survive in water containing less than 1.0-1.5% salinity, but can grow at lower temperatures than the teredines.

Many strategies have been developed for control of marine borers but, assuming that the piles have sufficient remaining strength, the most effective methods, such as concrete encasement, all work by reducing the oxygen content of the water around the borers.

2.4 Corrosion of fasteners

Corrosion of steel fasteners can cause serious strength reductions for two related reasons. Firstly, the steel fastener reduces in size and weakens; and secondly, a chemical reaction involving iron salts from the rusting process can cause defibration of the surrounding wood (note that this is not a fungal decay, but the softening process normally increases moisture ingress and leads to accelerated decay).

2.5 Shrinkage and splitting

Moisture can exist in wood as water or water vapour in the cell cavities, and as chemically-bound water within the cell walls. As green timber loses moisture to the surrounding atmosphere, a point is reached when the cell cavities no longer contain water, but the cell walls are still saturated with chemically-bound water. This point is called the "fibre saturation point". Wood is dimensionally stable while its moisture remains above the fibre saturation point (which is typically around 30% for most timbers). Bridges are normally constructed from green timber, which gradually dries below its fibre saturation point until it reaches equilibrium with the surrounding atmosphere. As it does so, the wood shrinks, but because it is anisotropic, it does not shrink equally in all directions. Maximum shrinkage occurs parallel to the annular rings – about half as much occurs perpendicular to the annual rings, and a small amount along the grain.

The relatively large cross-section timbers used in bridges lose moisture through their exterior surfaces so that the interior of the member remains above the fibre saturation point, while the outer layers fall below and attempt to shrink. This sets up tensile stresses perpendicular to the grain, and when these exceed the tensile strength of the wood, a split or check develops, which deepens as the moisture content continues to drop. As timber dries more rapidly through the ends of a member than through the sides, more serious splitting occurs at the ends. Deep checks provide an ideal environment for the introduction or acceleration of fungal decay.

Splitting can also result because of longitudinal shrinkage when the timber is restrained by a bolted steel plate or other type of fastening. This splitting can be avoided by allowing the timber to shrink freely by using slotted holes. As timber shrinks, it tends to lose contact with steel washers or plates, so the connection is no longer tight. Checking the tightness of nuts in bolted connections is therefore a standard item of routine maintenance for timber bridges.

2.6 Fire

Wood itself does not burn. The effect of heat is firstly to decompose the wood (a process known as "pyrolysis") and it is some of the products of this decomposition that burn if conditions are suitable. This concept is important in discussions on the action of fire retardants.

In theory, wood decomposes at temperatures as low as 20 °C (at the rate of 1% per century). At 93 °C, the wood will become charred in about 5 years.

When wood is heated, several zones of pyrolysis occur that are well delineated due to the excellent insulating properties of wood (thermal conductivity

roughly 1/300 that of steel). These zones can be described generally as follows:

- Zone A – 95-200 °C – water vapour is given off; wood eventually becomes charred.
- Zone B – 200-280 °C – water vapour, formic and acetic acids, and glyoxal are given off; ignition is possible, but difficult.
- Zone C – 280-500 °C – combustible gases (carbon monoxide, methane, formaldehyde, formic and acetic acids, methanol, and hydrogen) diluted with carbon dioxide and water vapour are given off; residue is black fibrous char; normally vigorous flaming occurs; if, however, the temperature is held below 500 °C, a thick layer of char builds up, and because the thermal conductivity of char is only 1/4 that of wood, the char retards the penetration of heat and thus reduces the flaming.
- Zone D – 500-1000 °C – the char develops the crystalline structure of graphite, glowing occurs, and the char is gradually consumed.
- Zone E – above 1000 °C – the char is consumed as fast as it is formed.

As the temperature of the wood is lowered, the above-mentioned behaviour still holds – eg. combustion normally ceases below 280 °C.

The numerical values quoted are approximate, and in practical situations may depend on many factors, such as the duration of heating and the rate at which oxygen is fed to the combustible gases.

Geometrical configuration is also very important. For example, a vertical stick less than 20 mm thick may burn due to elevated temperature from the bottom up without an external source of heat, but will not burn from the top down. A stick appreciably thicker than 20 mm will not burn unaided by an external heat source. Large section round timbers, as used in bridge construction, have good resistance to fire and, except during a severe bush fire, usually survive quite successfully.

When a timber element is heated above 280 °C, it chars at more or less a constant rate regardless of the value of temperature. Typical charring rates are 0.6 mm/min for softwood and 0.4 mm/min for hardwood. These rates hold reasonably true provided that the minimum dimension of the structural member is not reduced to less than 50% of the original.

The strength of a timber structural member during a fire depends on the portion of wood that has been charred, the temperature distribution in the sound wood, and the theoretical relationship between strength and temperature. To obtain the strength of structural members from these considerations is a complex analytical problem. However, research by Australian road authorities has shown that for most practical situations it is reasonably conservative to assume that the strength of burning sound timber is 80% of the value that it had before the burning commenced (Greaves, 1985).

3 PRESERVATION AND TREATMENT

An understanding of the timber deterioration risk factors leads fairly logically to the measures needed to combat them. Timber structures are not maintenance-free (and never should be so readily abandoned to the elements), and the most economical conservation/management plan for any structure involves a systematic performance of relatively simple preventive maintenance activities. The preservation plan for any individual structure must be tailored to suit the construction features, the environmental exposure factors and possible aesthetic restrictions.

3.1 Waterproofing and sealing

The simplest practices probably are those involving waterproofing, as dry timber cannot rot. Where moisture is well controlled, as in framed buildings, painting is at least as important for the durability of the timber as it is for its appearance. For any important structure, it is unwise to exceed the manufacturer's recommended interval for repainting and visual inspections of the coating integrity should be done at least annually.

Even where timber frames are exposed to the elements, such as in towers, bridges and the like, it is very important to seal all timber end-grain that has exposure to rain or high moisture levels. Water is transmitted along the grain of timber about 250 times more readily than it passes radially, so effective sealing of ends greatly improves durability. For bridge structures a two-coat sealing process is used – involving a penetrating waterproofer as the first, main coat, and then a flexible bitumen-based topcoat (particularly functioning as a UV shield to prolong the life of the first coat) – and such an enhanced sealing practice should be considered for more architectural structures wherever aesthetics allow.

3.2 Fastener maintenance

Framed structures are very dependant on the integrity of connections, and bracing systems must remain effective despite shrinkage of timber, bolt deterioration and hole enlargement due to timber deterioration. Bolts should be regularly tightened (at least annually at first), especially in the first few years of a structure when timber shrinkage is likely to be most marked. Anywhere fasteners are exposed to high moisture or rain, coating of threads and nuts in lanolin-based grease is highly advised.

Where timber members are founded in ground, such as with driven bridge piles, the moisture inside the

timber member is very high close to the ground line, and special efforts are necessary to avoid the mutual destruction wrought by the acidic timber and the chemically-active bolts associated with bracing systems. Although it can involve a lot of effort, Main Roads WA has made it standard practice to remove all bolts through buried timbers within 1 m of the ground line. This facilitates inspection, reinstatement and treatment of the hole, and is followed by fastener replacement (only if a replacement is deemed necessary) with a new bolt, separated from its timber surrounds by a PVC sleeve and lanolin-based grease.

3.3 Fungicide treatment (rot prevention)

Moisture cannot always be kept from timber, especially in exposed structures founded directly in soil. The development of diffusible boron-based fungicides in the past 30 years has played an important part in the ability to protect previously-untreated timber in service. It is vital to note that these boron fungicides are effective against a wide spectrum of decay organisms and attacking insects, including many termites, but are not as toxic or dangerous to use as most of the more well-known timber preservation methods. In WA, a conscious decision was made when choosing fungicide products for bridge maintenance to make sure that the materials be both safe to apply and also environmentally safe in order to avoid future disruption of treatment programs if products have to be withdrawn from the market.

The literature (Bunn, 1974; Edlund et al, 1983) states that boron fungicides are effective against most rots when present in timber at a Boric Acid Equivalent (BAE) loading of 1.5 kg/m^3 of timber. Due to the time required for diffusion to occur through timber after application, and the possibility of leaching losses of active ingredient, it has been usual to apply these borates in bridges at a BAE loading of at least 3.0 kg/m^3. The nature of leaching losses, especially in the ground line zone of timber piles, has meant that retreatment is necessary every 5 years for timber members in ground contact.

Boron fungicides are available commercially in a number of forms, all having some application to timber structures:

- Fused borate rods, such as Impel (anhydrous disodium octaborate). The most concentrated form of borate preservative, designed for relatively slow diffusion or applications where size of treatment reservoirs must be minimised.
- Cast borate/fluorite rods, such as Preschem Polesaver. Cheaper than the fused rods, but much less concentrated preservation medium than Impel. Suitable for applications where timber is moist, but not saturated, and larger treatment reservoir volume can be tolerated.
- Raw borate powder, such as Timbor, Solubor or Polybor (all disodium octaborate tetrahydrate). The raw material for the commercial fungicide formulations, this can be utilised by mixing in soil to form a fungal and insecticide barrier for timbers in direct soil contact – but should not be used where contact with living plants (such as around home gardens) is likely. Care is also advised in handling the finely ground powder, due to the health risks associated with all such fine dust materials. The borate powder may also be mixed into slurry form and pumped or poured into treatment reservoirs inside timber members.
- Solutions of borate in glycol solution (Dirol, 1988; Freitag et al, 2000), such as the Boracol range of products and equivalent preparations. Typically solutions of 10%, 20% or 40% W/W disodium octaborate tetrahydrate in a glycol solution, often with a 2% supplement of mouldicide such as benzalkonium chloride. All formulated for rapid diffusion, but prone to excessive leaching losses in saturated timbers with significant soil contact. The 10% and 20% solutions are very suited to spraying applications, and the 40% solution is advised for brushing on exposed timber surfaces or for pumping into drilled treatment reservoirs.
- Paste preparations of borate in glycol, such as the 80% W/W Hometeam Eco-Bor 80 Plus product. Still capable of reasonably rapid diffusion, these materials are intended for protection of large timber beams – where the volume of treatment reservoirs must be minimised to control effects on strength, and where the viscous nature of the preparation avoids leakage of fungicide through any splits and checks in weathered members.

It must be noted that these preservatives are only capable of protecting timber against the agents of deterioration, and cannot be used to reinstate timber that has seriously rotted or been consumed by organisms. The durability of the structure will be optimised by application of the preservative system at the earliest possible time, and reapplication at the intervals indicated in the *Main Roads Timber Bridge Preventive Maintenance Standards* publication (freely available through the Main Roads WA website; Margetts, 2004).

3.4 Treatment delivery methods

Most application methods are simple and can be delivered using an inexperienced workforce, such as the volunteers often associated with "heritage" projects.

The liquid solutions of fungicide can be easily and safely applied by brushing (to a specified loading or dosage rate) onto exposed timbers surfaces, or in

some cases sprayed onto the surface. Note that when surface application is specified, it is recommended that the timber be heavily wetted on the previous day to maximise the uptake of the diffusible material – borates in glycol solution are rapidly drawn into areas of high moisture content.

Note that a recent innovation in the use of 40% borate preparations (specifically Hometeam Industrial Timber Treat) utilises the diffusion of the borate over a period of several weeks. A disposable or biodegradable reservoir of approximately 1 L capacity is attached to a modest treatment hole in a member, such as a bridge stringer. Fairly simple to install, this is proving effective in minimising the labour input needed for the preventive maintenance task.

The thicker (40% and above) borate preparations are either pumped or brushed, as allowed by viscosity. For treatment of timbers buried in ground, such as bridge piles, the use of drilled treatment holes is advised to ensure the most efficient diffusion of fungicide through the "at-risk" ground zone. Care must be taken to thoroughly clean all pump equipment used for borate/glycol materials, as any glycol residue will attract airborne moisture and result in rapid corrosion.

The fused or solid fungicide rods are best applied into reservoirs drilled angled downwards into the timber member, with the holes capped (to avoid excessive moisture ingress) with proprietary plastic caps available from the fungicide suppliers. It has been common practice to "top up" treatment reservoirs with borate/glycol product to enhance the early diffusion of the solid borate rods.

When an advantage may be seen in sterilising soil adjacent to timber (such as when gravel road pavement exists over a timber bridge deck), it is recommended to remove the soil, mix with a measured dose of borate powder and water, and then re-compact as described in Activity Code 23 of the *Timber Bridge Preventive Maintenance Standards*. Mixing can be done with appropriate tools, ranging from hand tools up to motor graders, depending on the scale of the project.

3.5 Termite treatment

It is recommended, and usually mandatory, that termite treatments are performed by licensed pest control personnel. Where a body has a significant amount of pest control work to be done, and an in-house capability involved in structural assessment or maintenance, there should be consideration for having such personnel trained and licensed for the additional pest control task.

Modern termiticides are generally much safer in use and also much more effective than the dangerous chemicals, such as arsenic and organo-chlorides, which gained notoriety a generation ago. Baiting systems such as Exterra and Sentricon, utilising insect growth regulator chemicals, may be safely used for protection in the most sensitive environments. Where fast eradication of termite activity is required, a modern non-detectable termiticide, such as Termidor dust, is capable of colony extermination by simply contacting a few thousand live termites. Similarly, powerful non-detectable termite barrier systems can be created with either Termidor or Premise liquid termiticide.

4 INSPECTION OF TIMBER STRUCTURES

As with any engineered structure subject to elements of natural deterioration and wear, skilled inspection is necessary for assessment of the adequacy and the maintenance needs of large timber structures. Simple visual inspection can give a very good guide to the elements and zones of a structure likely to be at greatest risk, and sounding with a heavy hammer such as a "gympie" hammer can inform the trained observer of the presence of hidden decay, hollows, checking and internal termite damage.

Wherever an accurate determination of structural capacity is needed to certify structural adequacy or to quantify which timber elements may need repair or replacement, it is necessary for a more empirical investigation using the minimum amount of disruption/damage applicable to the scale of structure.

A well-established inspection methodology for timber bridges involves drilling all critical sections of structural elements using power drills with long bits of around 10 mm diameter. Condition assessment is possible by observing the consistency of the drill shavings, as well as feeling the resistance of the bit as it penetrates the timber section. One advantage of this testing method is that the same inspection holes can serve for finding active termites (they usually appear at the surface of the hole within a minute or two) and also for treating termites if the inspector is licensed to do the dusting. Note the need to expose and drill below the ground line when foundation timbers are buried or driven into soil – and further note possible secondary ground line effects when the ground line changes after the structure enters service (this circumstance is common in bridges when flood flows erode the river bed, but similar effects may occur when the use of structures changes).

A recent development in drill inspection technology for timber is the micro-drilling technique, as represented by the Sibtec Digital Microprobe and the Resistograph tools. Both tools operate by rotating a small diameter probe at high speed into timber and making a graphical plot or a digital record of the resistance encountered at any stage. The precision of these tools is quite high (they can detect growth rings in living trees) but they still need to be used with care to ensure that the readings are properly

representative of the section under investigation. An obvious advantage of the micro-drill method is the much reduced damage associated with the small probe, as compared with the traditional drilling inspection.

Where any form of damage to the timber appearance cannot be accepted, a degree of assessment is possible using non-destructive tools such as ground penetrating radar (GPR), computer tomography (CAT scanning) or variants of ultrasound investigation. Unless a tool such as a medical CAT scanner is used, these tools generally lack the precision of micro-drill investigation, but they can give a very useful picture of the general degree and distribution of density variation within a timber section, and hence allow an experienced observer to estimate factors like deterioration and strength.

Structural assessment of large engineered timber structures should be done with an understanding of the deterioration risks associated with that structure and a knowledge of the preventive maintenance measures applicable to the structure (and likely to be used if specified). It is no longer a reasonable assumption that a timber member cannot be durable merely because it is exposed to the elements, and any structural report for a timber structure of heritage interest should list the preventive maintenance measures that will be needed to keep the structure in a sound condition.

4.1 Innovative repairs and strengthening

The management of any large historic structure raises discussion of the desire to accommodate modern design loadings and safety standards in a deteriorated structure that was designed to lesser standards. The philosophy of non-original strengthening will not be addressed here, but it is worth commenting on the use of "leading edge" technologies for timber because of the dramatic rise in use of modern composite materials such as carbon fibre, glass fibre and Kevlar.

Carbon fibre is a very strong, lightweight material, having much potential for strengthening many traditional building materials, including timber – and has a particular attraction for use in heritage work where a small amount of strengthening material might be both effective and unobtrusive. Whether used as a woven fabric or as a formed laminate, the carbon fibre product has proven strength, but the factor that will define the strength and durability of the application is the resin formulation of the glue and its long-term interaction with the parent material of the structure. Care must be taken to specify a resin that will be compatible with the environment and conditions that will be faced both at the time of application and through the life of the structure. The effect of preservative use in timber substrate must also be considered, as some glue resins may not be compatible with the fungicides needed to keep the substrate in sound condition.

5 CONCLUSION

A conservation methodology has been developed for timber bridges, founded on regular skilled inspection and engineering assessment of structures, and underwritten with a comprehensive program of preventive maintenance activities. The measures described are easily adapted to enable the safe and economical conservation of most timber structures, including many of those large timber structures whose retention has been classified as "too hard". The maintenance activities are generally simple and safe to perform, bringing the conservation task within the performance range of the local or volunteer workforce so often associated with heritage conservation projects. The preservation of timber structures is considerably cheaper and easier than the restoration of such structures after sustained neglect, and bodies with an interest in significant large timber structures should facilitate preservation measures as soon as the significance of the structure is established.

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Has been closely involved in bridge management issues, specialising in timber bridge maintenance since 1986. His current title is Structures Delivery & Standards Engineer.

Between 1987-1990, Lloyd was prominent in the development of preservation practices for timber bridges using diffusible preservatives and other materials of low environmental impact. He drafted the timber bridge maintenance sections for the *Austroads Bridge Management Manual* in 1989-1990.

Lloyd has been an active member of the Engineers Australia's WA Engineering Heritage Panel since 1987. He was on the committee that produced the *Austroads Guide to Heritage Bridge Management*, was responsible for the bicentennial restoration of the 1870 timber bridge over Munday Brook on the Mason & Bird tramway, and has been involved in many other restoration projects, including Donnelly River Mill.

He first drafted the *WA Timber Bridge Preventive Maintenance Standards* publication in 1995 and has done a number of revisions of the manual, which sets out how to preserve timber bridges.